AN INTEGRATED APPROACH TO MILITARY AIRCRAFT SELECTION AND CONCEPT EVALUATION

Dr. Dimitri N. Mavris*
Associate Director & Manager, Aerospace Systems Design Laboratory (ASDL)

Mr. Daniel DeLaurentis†
NASA Multidisciplinary Analysis (MDA) Fellow, ASDL

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0150

Abstract

The design (or evaluation) of military aircraft, by nature, is a process consisting of conflicting goals and objectives at the conceptual, preliminary, and detailed level. Affordability, mission capability, availability (operational readiness), wartime survivability, and peacetime safety are five of the main attributes required of modern weapon systems. Traditional approaches for system evaluation or optimization have focused on one, perhaps two, of these attributes in isolation. At Georgia Tech's Aerospace Systems Design Laboratory (ASDL), a methodology has been developed which takes account of the combined effect of each of the "-ilities" plus safety in providing a means to evaluate alternative designs. The centerpiece of this approach is the Overall Evaluation Criterion (OEC). The OEC is an equation consisting of five metrics; one for each of the attributes. These five terms are pre-multiplied by so-called attribute importance coefficients which represent the ability to tailor the OEC to the evaluator's preferences. The purpose of this paper is to detail the form of this OEC, describe the appropriate metrics for each of the five attributes which make up the criterion, illustrate an algorithm for their concurrent calculation, and conclude by suggesting a novel way of quantifying an evaluation by accounting for the "voice of the customer".

Nomenclature

A_i	= Inherent Availability
IPPD	= Integrated Process and Product Development
LCC	= Life Cycle Cost
MCI	= Mission Capability Index
MTBF	= Mean Time Between Failure
MTTR	= Mean Time To Repair
P_D	= Probability of Detection
$P_{H/D}$	= Probability of Hit if Detected
$P_{K/H}$	= Probability of Kill if Hit
P_{surv}	= Probability of Survival
EAI	= Engine Attrition Index
O&S	= Operations and Support cost
OEC	= Overall Evaluation Criterion
PI	= Productivity Index
P_s	= Specific Excess Power
RDTE	= Research, Design, Development, & Test
k	= mission capability weighting factor
α	= affordability importance coefficient
β	= mission capability importance coefficient
γ	= operational safety importance coefficient
δ	= survivability importance coefficient
ε	= readiness importance coefficient

Introduction

The definition of a "good" overall design for a military weapon system almost always depends on one's point of view. From a performance standpoint, a necessary requirement for an advanced multirole strike aircraft, for example, is a significant ground attack capability in the form of delivering a maximum payload to a target at an appropriate range as well as some air-to-air capability at certain Mach-altitude combinations. The resulting size and geometry of such an aircraft, however, may result in a poor level of survivability due to increases in radar and infrared signature. Further, passive improvements in these signatures may dramatically drive up the aircraft cost. The recognition of these tradeoffs is not difficult; it is, however, not trivial to capture and quantify them for the purposes of design and/or evaluation. It is for this reason that the methodology described herein was constructed.

The paper is constructed in the same order as one would execute the methodology described. First, the task to be accomplished is defined and value objectives are formulated. Then, feasible alternatives are either evaluated (if they already exist) or generated for new designs based on these objectives and mission requirements. These alternatives are then evaluated against each other via the Overall Evaluation Criterion. Finally, a summary flowchart of the approach is presented along with concluding remarks.

---

* Member, AIAA

† Graduate Student Member, AIAA

Presented at the 1st AIAA Aircraft Engineering, Technology, and Operations Congress, Los Angeles, CA, September 19-21, 1995

Decomposition: Establish the Objective

The methodology development task was first approached from a system level viewpoint. What attributes contribute to weapon system effectiveness? Previous studies have considered such elements as payload / range capability, maneuverability, signatures, and operating cost to name a few. In fact, most of these studies have evaluated system effectiveness by accounting for these elements in isolation. The approach taken presently is based on the idea that the only way to measure or evaluate total system effectiveness is through an overall evaluation criterion which captures or addresses all key elements. In essence, the desired criterion function must allow the designer or the evaluator to ask and answer such questions about a set of feasible configurations as:

- How much does it cost to manufacture, operate, and maintain this system(s) ?
- Can this aircraft deliver sufficient payload to target ? Is an increased-range variant possible ?
- What are the differences in maneuverability between the candidate configurations?
- What are the relative operational availability levels? What is the reliability of each aircraft?
- How survivable are the candidates?
- What are the corresponding peacetime attrition rates?

The consideration of these questions calls for a breakdown of weapon system effectiveness into appropriate headings. It was decided that a scheme similar to the one advocated by the Defense Systems Management College (DSMC) would be used to address such questions. Therefore, the detailed DSMC system effectiveness breakdown structure found in Reference 1 was studied and subsequently modified with the inclusion of affordability to better represent the scope of today's weapon system procurement environment. This modified decomposition provides for a more natural means of implementation when the time comes to perform actual analysis. This breakdown for a military aircraft appears in Figure 1.

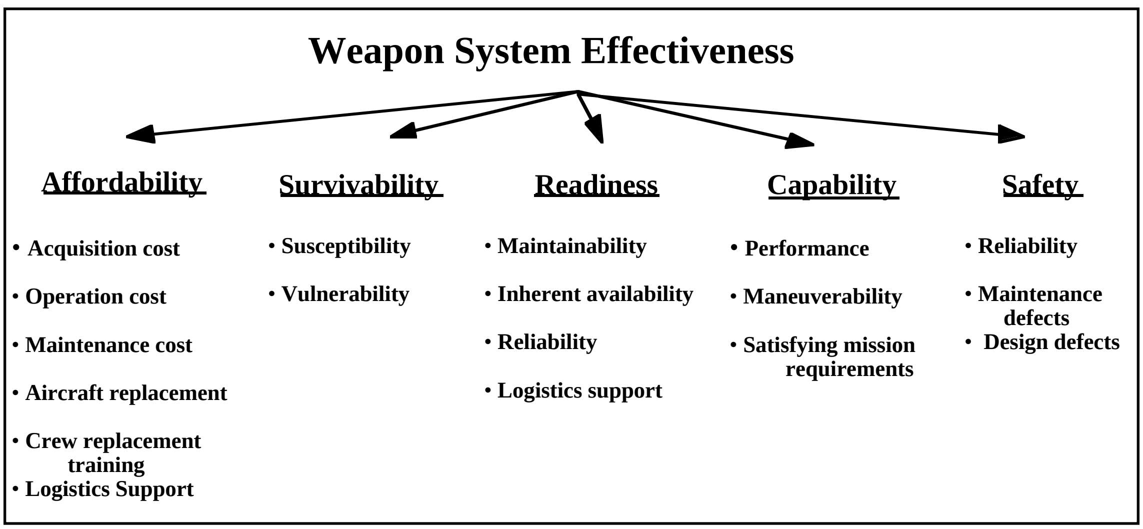


Figure 1: Weapons System Effectiveness Chart

With this breakdown in hand, one can begin to form ideas as to how best to evaluate the "goodness" of competing configurations. Before any evaluative task is undertaken, however, whether it be an optimization or series of point design evaluations, an objective function needs to be defined. Objective functions are usually mathematical representations of a physical phenomenon which are desired to be studied. For strike aircraft, as an example, a common objective function might be range for a given payload. For an air superiority aircraft, its maneuverability characteristics would be a more appropriate measure of comparison. Many times, however, a discipline specific function is neither desired nor appropriate, and a purely physical objective function which represents the total weapon system merit is not available. Instead, an *inclusive* criterion is needed to accurately capture the correlation between component characteristics and System Effectiveness. Therefore, such an inclusive function can be formulated and simply referred to as the Overall Evaluation Criterion.

Given that the general attributes of a weapon system appropriate for the criterion function have been identified (Fig. 1), a formal expression for this OEC is developed. This is accomplished through the use of *discipline metrics*. A metric is a means of transforming a set of dependent variables into a standardized statistic so that multiple dependent variables can be investigated and evaluated simultaneously.[2] The five major attributes of a weapon system, as in Figure 1, are:

- Affordability
- Mission Capability
- Operational Safety
- Survivability
- Operational Readiness

As such, the general form of the OEC is as follows:

$$OEC = \alpha(\text{Affordability}) + \beta(\text{Capability}) + \gamma(\text{Operational Safety}) + \delta(\text{Survivability}) + \varepsilon(\text{Readiness}) \quad (1)$$

The OEC is then formally defined by selecting five discipline metrics, each of which represents one of the five key attributes. The α, β, γ, δ, and ε are the aforementioned attribute importance coefficients and must always sum to unity. These coefficients provide the ability to tailor the OEC to specific needs, preferences, or points of view of a customer. In other words, given one dollar, the coefficients indicate how the evaluator would want to distribute that dollar. The focus now turns toward developing the five discipline metrics to complete the OEC.

Affordability

Affordability is measured by the Life Cycle Cost (LCC) metric. Since all newly proposed military aircraft programs will most certainly be scrutinized with regard to affordability, the aircraft designer must become aware of how his decisions affect the economics of the program. In fact, if an affordable system is to be built, the designer will have to account for economic considerations from the conception of the program until the retirement and disposal of the aircraft. LCC can be defined as the total cost to the government of acquisition, ownership, operation, and disposal of that system over its full life.[3] As such, it includes the following: Research, Development, Test, & Evaluation (RDT&E); Production; Operation and Support (O&S); and Retirement and Disposal. The following equation illustrates the terms that make up the Life Cycle Cost:

$$LCC = RDT\&E + Procurement + O\&S \quad (2)$$

Although the general equation is simple, the make-up of the component parts is quite detailed. Many times it is valuable to decompose a metric into its various sub-models and input parameters. This can be done via an Ishikawa, or "Fishbone" Diagram, as seen in Figure 2. The upper portion documents the top level costs which appear in the equation. The bottom charts the second level costs (e.g. component, material cost).

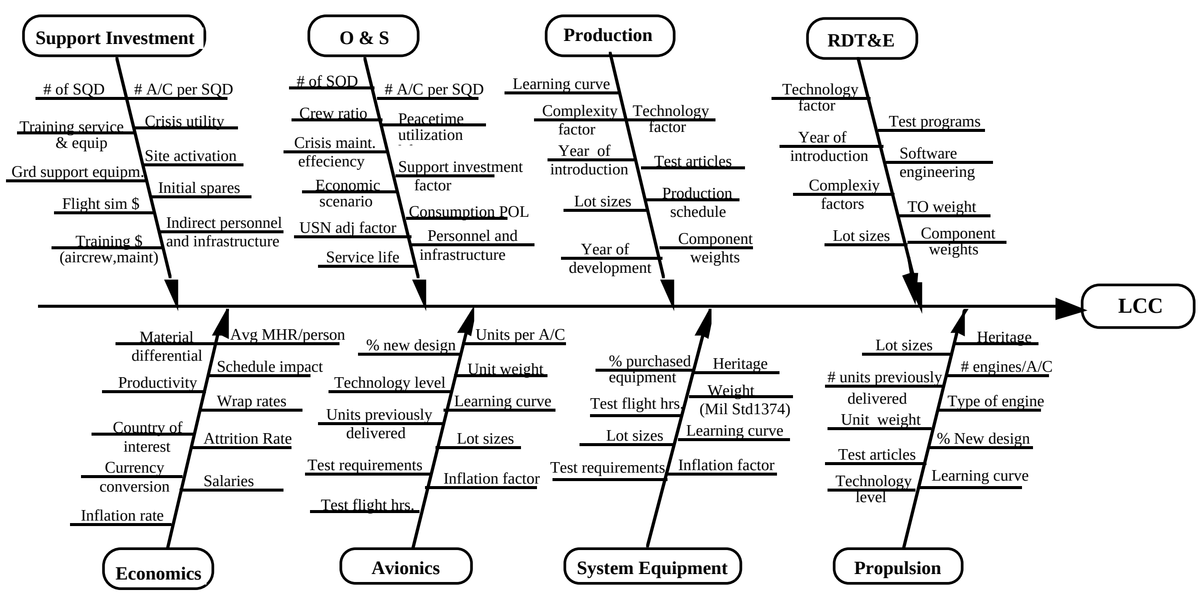


Figure 2: Ishikawa Diagram for Life Cycle Cost

The Ishikawa Diagram helps illustrate that the LCC will be influenced by Attrition Rate (attrition aircraft needed), Operational or inherent availability (maintenance times, failure rates), Capability (component weights, fuel requirement), and Survivability (low observable geometry, coatings, electronic warfare equipment). These couplings are captured by the fact that each term influencing LCC is also represented in the OEC. Thus, for example, the "price" of a high attrition rate will be felt in the procurement cost and the cost of a stealthy design will appear in the development and procurement costs.

Mission Capability

Mission Capability is a measure of an aircraft's ability to complete its mission (satisfy or exceed all mission requirements). Unlike affordability, where a widely accepted metric (LCC) exists for comparison purposes, the mission capability area lacks such a comprehensive metric. Therefore, a somewhat "artificial" one needs to be created. Given a baseline set of mission requirements and assumptions, the performance of various configurations can be compared through a Mission Capability Index (MCI). The capability of a multirole aircraft consists, at a fundamental level, of two types of performance requirements: air-to-air and air-to-ground. The MCI, then, consists of two terms: the Performance Index (PI) and excess Power (P_S). The PI is a function of payload, range, empty weight, and fuel weight. Thus, the PI can be viewed as a measure of *air-to-ground* capability, i.e. how much payload can be delivered to a target, and what effect such capability has on the overall weight and size of the aircraft. The PI is displayed in Equation (3):

$$PI = \frac{\text{Payload} \times \text{Range}}{(W_{Fuel} + W_{Empty})} \tag{3}$$

The P_S is the Specific Excess Power, which is a function of available thrust, total drag, flight speed, and the weight and is measured at specified Mach number, altitude combinations. The expression for P_S is shown below in Equation (4).

$$P_s = \frac{(T - D)V_\infty}{W} \tag{4}$$

P_S can be viewed as a measure of energy available to the aircraft to perform a maneuver. A positive P_S implies energy is available to tighten turns, climb, or accelerate. On the other hand, negative P_S implies an energy loss to decelerate, dive, or slow in a turn. Finally, a P_S equal to zero means that the point of maximum sustained turn or sustained level flight (T=D) is reached. For calculations leading to the inclusion in the OEC, P_S should be measured at the critical performance points. Its relation to accelerations, turn rates, etc. makes P_S a good measure of *air-to-air* capability.

As depicted in Equation (5), the MCI contains weightings on the air-to-ground and air-to-air terms, achieved through the use of the constant *k*. The *k* factor ranges between zero and one, where a large value of *k* stresses the air-to-ground aspect of capability and a low value of *k* stresses the air-to-air aspect. If *k* is set to zero, then the aircraft is considered to be a pure air-to-air fighter, while when *k* is set to one, the process yields a pure strike or air-to-ground vehicle. This *k* factor can be assigned based on the mission design requirements (i.e. $k > (1-k)$ for a multirole strike aircraft and $k < (1-k)$ for a fighter / interceptor).

$$MCI = k\frac{PI}{PI_{BL}} + (1-k)\frac{P_s}{P_{s_{BL}}} \tag{5}$$

Operational Safety

Operational Safety is the third component in the OEC, and in many ways is one of the most difficult to evaluate. By nature, any study of safety is reduced to an exercise in the investigation and analysis of historical data. However, whatever inferences are drawn from the data can and will influence the outcome. Further, in the real region of interest (i.e. wartime), the sample data population is small and imprecise, especially for modern military aircraft, and is heavily dependent on threat scenario / circumstances making it extremely hard to uniformly assess or quantify.

There are several key operational safety definitions that need to be identified preceding the safety analysis. According to the terminology used by the safety community, an *incident* is any occurrence which leads to an unsafe or potentially unsafe situation. Incidents, or mishaps, which result in damage or injury are classified according to the severity of the occurrence. There are three levels of severity: Class-A, Class-B, and Class-C.

A *Class-A mishap* is an occurrence in which there is loss of life, the aircraft is destroyed, or the total damage to the aircraft exceeds one million dollars. A *Class-B mishap* is an incident in which there is a severe injury or the total damage to the aircraft exceeds $250,000 dollars but is less than one million dollars. *Class-C mishaps* are the least severe and occur when there is a minor injury or the total damage to the aircraft is less than $250,000 dollars. Figure 3 depicts the relative number of mishaps that occur for every one Class-A occurrence. For example, for every Class-A mishap, there are 10 Class-B mishaps, and so on.[4]

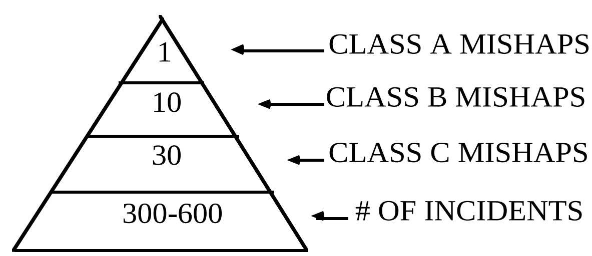


Figure 3: Relationship of the Occurrence of Incidents and Mishaps

The Class-A mishap category is widely used and is the same for both the U.S. Air Force and Navy. In contrast, the definition of the other two classes has changed with time, or is different between services.

The frequency of these accidents are generally defined in terms of mishap rates, which are defined as the number of mishaps occurring within a given number of flight hours. The worst mishap rates for aircraft occur in the first few thousand flight hours. After this infancy period, inherent design problems are discovered and corrected, and both the operators and the maintainers become better acquainted with the aircraft and its sub-systems. Thus, as flight hours build up, the system is said to mature. It is generally accepted that an aircraft reaches maturity after 1 million fleet cumulative flight hours.

Returning to the key definitions, two critical ones are attrition and engine caused attrition. *Attrition* is defined as the loss of an aircraft, which translates into a reduced capability to advance mission objectives and possibly loss of life Attrition is expressed in terms of losses per 100,000 flight hours, and its calculation is as follows:

$$\text{Attrition} = \left(\frac{\#\ \text{A / C Lost}}{10^5\ \text{Hrs.}}\right) \bullet\ \text{Flight Hours} \qquad (6)$$

Since the majority of Class-A mishaps are destroyed aircraft, and both services have the same definition for Class-A, use of this group of incidents yields consistent results. Often, however, the exact details of the cause of a wartime Class-A mishap are simply unavailable. It is for this reason that a safety evaluation analysis may have to be based on peacetime attrition data. In this setting, the *Engine-caused Attrition Index* (EAI), as illustrated in Equation (7), presents a means of estimating the effect on peacetime attrition of engine induced Class-A failures based on the total number of aircraft operated. In terms of peacetime safety concerns, engine related causes dominate the attrition profile; thus the EAI is appropriate.

$$\text{EAI} = \frac{\#\ \text{A / C Procured}\ -\ \#\ \text{Engine Caused Attrition A / C}}{\#\ \text{A / C Procured}} \qquad (7)$$

This index is a function of the number of aircraft procured and the number of aircraft lost due to engine causes. *Engine-caused mishaps* are incidents where primary failure was solely initiated and chargeable to the engine or its components. From an engine attrition point of view, the higher the EAI value, the safer the system. This category does not include engine failures due to improper maintenance or operation.

Though tempting, it is quite dangerous to blindly collect what seems to be appropriate data for use in calculating a safety metric such as the EAI. Historical safety data can quite easily be misused to support one's point of view. The existence of a multitude of possible causes for attrition as well as the frequent difficulty in discerning the cause of a Class-A mishap contributes to the confusion. In order to understand this "confusion", one needs to examine the factors that generally influence attrition and explore the nature of mishaps with the hope of computing an accurate EAI.

Mishaps can be viewed as a function of the following attributes:

- Technology Level → Year of Introduction

Measured by

- Maturity → Total hours flown

Which translates to

- Operational Env. → Land vs. Carrier
- Mission Type → Strike, Air-Air, Bomber
- Mission Scenario → Night, Day; Low, High
- Crew Size → One vs. two pilot crew
- Commonalty → airframe, engine
- Engine Number → Single Vs. Twin

Therefore, an objective comparison of configurations with respect to one attribute, for example operational environment, can only be made when all causes of variability are removed from the data gathered. If possible, the effect of operational environment must be isolated to allow the proper assessment of data based upon a common mission type, crew size, and number of engines. The more difficult task is discerning the fashion in which technology level and maturity level can be addressed and consequently normalized. For comparison of future concepts, though, the Class-A engine related mishap rates used in computing the EAI must be based on a projection of engine technology improvement.

Survivability

Survivability can be broadly defined as a measure of an aircraft's ability to evade detection and avoid damage which would result in loss of vehicle. A complete assessment requires a multivariable functional analysis over the spread of possible missions and threats, as described by R. E. Ball in *The Fundamentals of Aircraft Combat Survivability Analysis and Design*, published by the AIAA. As shown in Figure 4, this procedure leads to the computation of a Survivability Index.

To quantify Survivability, the probabilities of being detected, hit if detected, and killed if hit must be considered. The aircraft's probability of survival, P_{surv}, can be divided into two parts, susceptibility and vulnerability. Susceptibility is the product of the probability of detection P_D and the probability of being hit if detected $P_{H/D}$. Vulnerability, on the other hand, is the probability of being killed if hit $P_{K/H}$. The product of these probabilities is subtracted from one to give the Probability of Survival, P_{surv}, shown in Equation (8).

$$P_{surv} = \left[1 - \left(P_D \cdot P_{H/D} \cdot P_{K/H}\right)\right] \qquad (8)$$

where P_D = Probability of detection
$P_{H/D}$ = Probability of being hit if detected
$P_{K/H}$ = Probability of being killed if hit

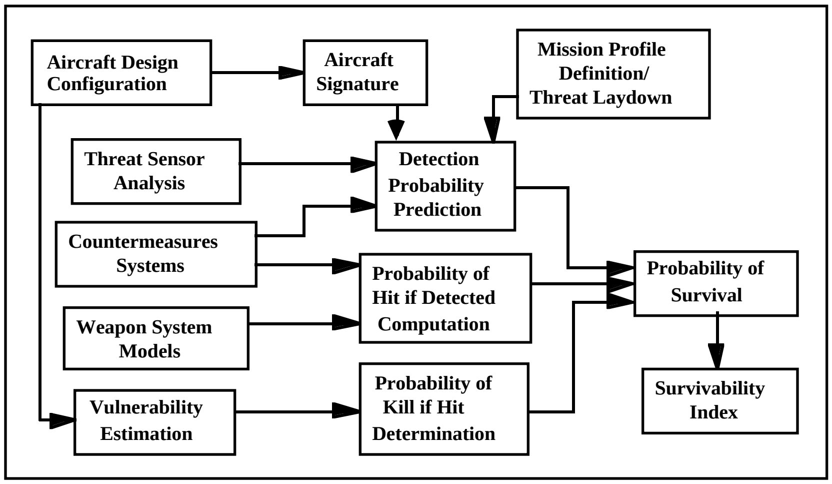


Figure 4: Flow Chart for Survivability Analysis

The individual constituents of the P_{surv} expression are determined mainly through such measures as radar cross-section, infrared signature, and electronic counter-measures effectiveness. Changes in aircraft configuration, such as the decision to use one engine or two, enter into the model of combat survivability assessment, along with such items as mission profiles and threat information. The estimated aircraft signature and the mission profiles allow survivability evaluation using estimates for probability of detection and the conditional probabilities of being hit if detected and of being killed if hit. Combat survivability also requires appropriate models for threat sensors, countermeasures, weapons systems, and aircraft vulnerability. The probability of survival can be calculated for a number of postulated mission profiles, and the overall survivability index is calculated from the span of probabilities of survival for different missions and different aircraft configurations.

Operational Readiness

Operational Readiness measures the amount of time a weapon system is ready and capable to perform the mission or function for which it was organized or designed. Military aircraft reliability is critically important to weapon system effectiveness, especially as seen through two commodities: time and money. An unreliable aircraft that is not mission capable for a wing commander, when he needs it, is not an asset to him regardless of performance or cost. Furthermore, this unreliable aircraft consumes resources, time, money, and manpower in order to provide support for repairs. Thus, reliability is directly linked to support costs, operational readiness, and availability. In fact, there is an equivalency between reliability and readiness or availability. Reliability is a design objective while availability is an operational objective. Operational availability can be viewed as a subset of operational readiness, since a commander can rearrange his assets (aircraft, crew, etc.) in such a fashion as to maintain high operational readiness levels although his operational availability may not be as good.

Operational availability, A_o is commonly defined as:

The long term steady-state availability of a system or equipment operating in its usual environment and performing required missions or functions. [5]

Mathematically, the operational availability is a function of the Mean Time Between Downing Events (MTBDE) and the Mean Time To Restore a System (MTTRS). The relationship between them is:

$$A_o = \frac{\text{MTBDE}}{(\text{MTBDE} + \text{MTTRS})} \qquad (9)$$

MTBDE represents the mean time between maintenance actions and ready time. MTTRS includes active maintenance time (MMH/FH) at the Organizational

(‘O’) level and at the Intermediate (‘I’) level, as well as the waiting (or pipeline) times for spares to arrive. The definitions above come from Reference 5.

Although operational availability is an appropriate metric for reliability, its definition includes, in addition to preventive and corrective maintenance, logistics and administrative downtime. These latter two aspects are hard to quantify, and in reality, have nothing to do with respect to how reliable the product is. In the limiting case, where the pipeline times and preventive maintenance are not considered, the operational availability reduces to the *Inherent Availability*.

The most common definition of inherent availability is:

A measure of the degree to which an item is in the operable and committal state at the start of the mission when the mission is called for, at an unknown time. [5]

Inherent availability differs from operational availability in that the former is a function of design related (or corrective) maintenance issues, whereas the latter represents both corrective and preventive maintenance. The evaluation of inherent availability consists of system differences in terms of reliability and maintainability. The equation for inherent availability is, thus, a function of the Mean Time Between Failure [MTBF (reliability)] and the Mean Time To Repair [MTTR (maintainability)] and does not encompass stockouts, administrative delays, and preventive maintenance. The equation for calculating the inherent availability (A_i) is given in Equation (10):

$$A_i = \frac{MTBF_i}{(MTBF_i + MTTR_o)} \qquad (10)$$

Both the MTBF and MTTR represent the *time* element of readiness, which is an important factor for wing commanders concerned about the amount of time their assets are ready to perform. For new concepts, such data can be carefully inferred from data on modern aircraft of similar type. The money aspect, measured in terms of maintenance man hours per flight hour (MMH/FH), is captured directly in the support part of the Life Cycle Cost analysis.

The expression for the OEC is now completely defined in terms of the attribute metrics. The five metrics appearing in Equation (11) represent the relative performance of competing configurations. Each of them has been introduced in the preceding paragraphs and are summarized in Table 2.1. The individual metrics are normalized by baseline values so that each term in the OEC is non-dimensional, thus avoiding the pitfall of "adding apples and oranges". Through this OEC, aspects previously unaccounted for in earlier studies are considered through *definable and traceable* metrics. This ensures a *comprehensive* assessment where direct, meaningful comparisons of competing alternatives are possible. The details of attribute metric calculations depend on the type of aircraft, the analysis tools available, and the level of sophistication desired. A generic way to approach these calculations is presented next.

$$OEC = \alpha\underbrace{\left(\frac{LCC_{BL}}{LCC}\right)}_{\text{Life Cycle Cost}} + \beta\underbrace{\left(\frac{MCI}{MCI_{BL}}\right)}_{\text{Mission Capability Index}} + \gamma\underbrace{\left(\frac{EAI}{EAI_{BL}}\right)}_{\text{Engine Related Attrition Index}} + \delta\underbrace{\left(\frac{P_{surv}}{P_{surv_{BL}}}\right)}_{\text{Survivability}} + \varepsilon\underbrace{\left(\frac{A_i}{A_{i_{BL}}}\right)}_{\text{Inherent Availability}} \qquad (11)$$

Table 2.1. Overall Evaluation Criteria Term Definitions

Attribute	**Metric**	**Expression**
Affordability	LCC	LCC=RDTE+Procurement+Operations and Support
Mission Capability	MCI	$MCI=k*PI+(1-k)P_s$
Operational Safety	EAI	$EAI = \frac{\#\ A/C\ Procured\ -\ \#\ Engine\ Caused\ Attrition\ A/C}{\#\ A/C\ Procured}$
Operational Readiness	A_i	$A_i = \frac{MTBF_i}{MTBF_i + MTTR_o}$
Survivability	P_{surv}	$P_{surv}=1-[P_D*P_{H/D}*P_{K/H}]$

Recomposition: Generate the Alternatives

Once appropriate metrics have been selected and the objective formulated, how does one approach calculating them concurrently? At Georgia Tech, a method has been constructed to do this, and can best be seen as a recomposition process employed once the various parts of the problem have been broken down and analyzed. In order to do this recomposition in an intelligent way, *Product* and *Process* design variables and constraints must be considered simultaneously. Product characteristics are those that pertain directly to the subject of design, such as geometry, materials, propulsion systems, etc. Process characteristics, on the other hand, refer to those items related to how a product is designed, produced, and sustained over its lifetime. At Georgia Tech, these different yet closely coupled characteristics are combined in the form of an Integrated Product and Process Design (IPPD) approach. This approach to weapon system evaluation takes the form of a "Funnel", as illustrated in Figure 5. In essence, the Funnel represents a concurrent recomposition process in which the various disciplinary interactions are accounted for during "synthesis", or recomposition. The Funnel shown in the figure would be used to evaluate existing configurations. For the evaluation and optimization of *totally new* concepts, the Discipline Level in the figure would contain actual design variables such as wing area, span, aspect ratio for aerodynamics, number of spars and ribs and percent composites for structures, etc., instead of the broader configuration characteristics shown.

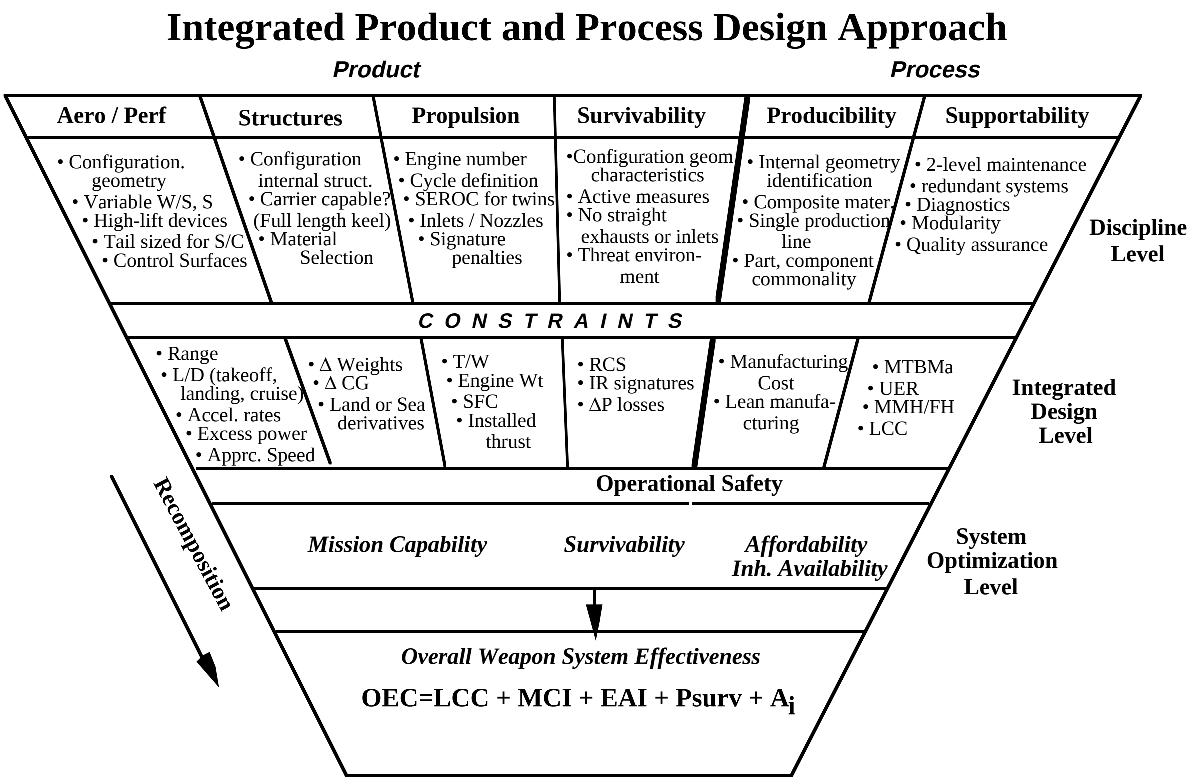


Figure 5: An IPPD Approach to Weapon System Evaluation

In any case, at the Integrated Design Level, Discipline Level information is used to perform system synthesis (with appropriate constraints). What is thus obtained are the various sub-metrics needed to calculate the OEC-level metrics for a given configuration. A similar procedure also takes place on the process side of the funnel, labeled as Producibility and Supportability. Through a recomposition of these disciplines, the system metrics for affordability, capability, and survivability are computed. With the inclusion of the safety and reliability data obtained through an analogy of historical data, the ultimate objective, the OEC, can be calculated. Since some of the computations for these last two attributes involve only analyses of historical data, much of the analysis related to them can be performed concurrently with the vehicle sizing and cost estimating tasks.

The IPPD approach in Figure 5, coupled with the multi-function OEC of Equation (11), can be utilized in two ways. For the evaluation of existing or derivative concepts, the methodology can be used as an inclusive, flexible assessment technique. If desired, however, the methodology can be extended to include the generation, evaluation, and optimization of totally new aircraft concepts based on a certain set of design requirements. Such a process has been developed by the ASDL for commercial sub- and supersonic transports.

<u>Problem Closure:</u>
<u>Evaluation via the OEC Decision Matrix</u>

The approach described in this paper attempts to retain as much decision freedom for the designer and customer for as long as possible. Ultimately, however, decisions must be made. Given the results for each of the areas investigated (affordability, capability, operational safety, survivability, and operational readiness), one would like to know which of, say Aircraft A and Aircraft B, is the better vehicle. Figure 6 illustrates that, if the choice was made in isolation, the answer to this question could be A, B, or inconclusive. This uncertainty is due to the lack of knowledge about the magnitude of the superiorities (how much better is A over B for Affordability) as well as the importance of the attribute (how important is Affordability to the overall objective).

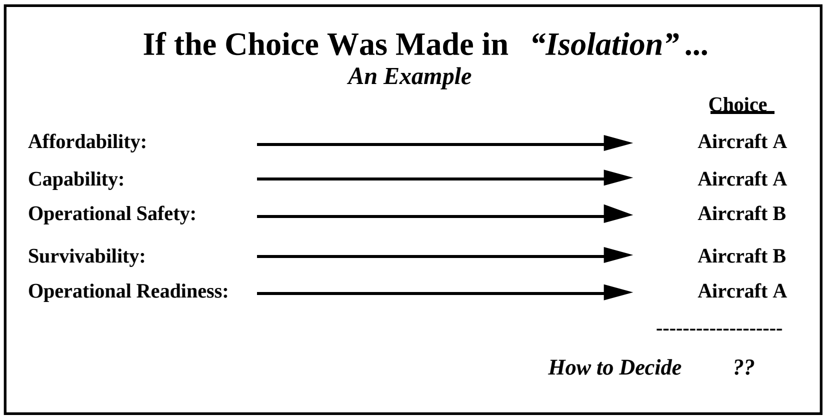


Figure 6: Isolated Design Decision Making

An alternative perspective to compare the Aircrafts A and B is obtained via the "Spider Chart" depicted in Figure 7. The values along the inner ring represent minimum acceptable values for that particular characteristic. Here, Aircraft A represents the baseline, since it takes a value of one for all of the measures. Aircraft B is then placed relative to that baseline. The outer ring represents normalized target, or ideal, values for this type of aircraft.

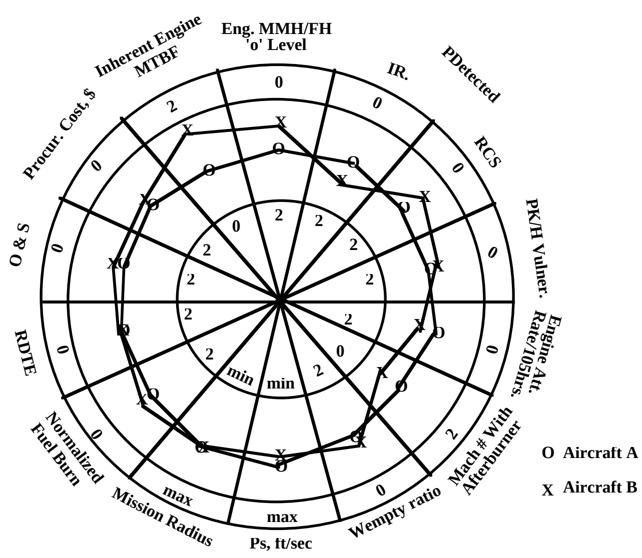
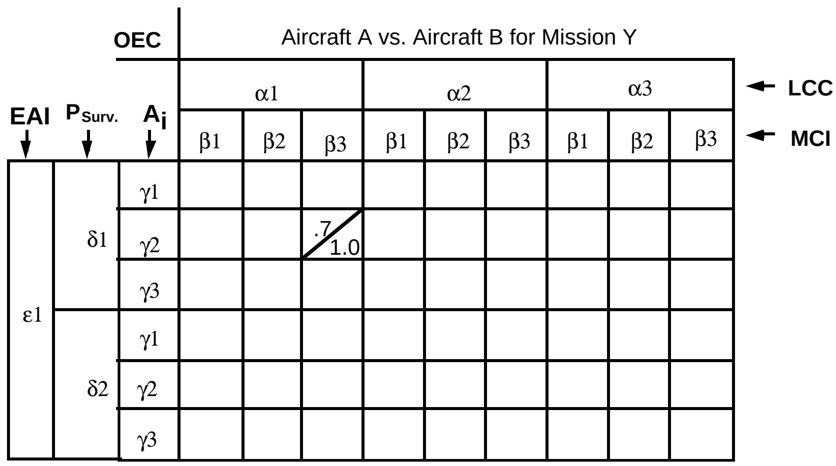


Figure 7: The "Spider Chart" View of System Evaluation

In other words, the better aircraft for each attribute "slice" will be to the outside of its counterpart. With these definitions in mind, Figure 7 exhibits in a graphical way the fact that our ficticious Aircraft A exceeds configuration B in all but four attributes, since it lies "outside" of Aircraft B the majority of the time. The "Spider Chart" can also show qualitative relationships between related characteristics. Figure 6, for example, shows an almost even exchange in the probability of detection, with Aircraft A having just about as much of a percentage advantage in IR signature as it does a disadvantage in RCS. Note that all of these results agree with the "isolated" conclusions concerning the five attributes in Figure 5. But the "Spider Chart" comes closer to capturing the entire system evaluation problem. The question remains, though, what if certain attributes were of higher importance to the evaluator or crucially important in the selection of a particular type of weapon system? Here, the "Spider Chart" fails and an alternative is again needed.

This shortcoming points in a direct way to the conclusion that the most effective and comprehensive way to evaluate the alternatives is through a well-formulated criteria function, in this case the Overall Evaluation Criterion (OEC). As mentioned previously, any system evaluation result is a function of two elements: the system itself and the *perspective* of the individual or organizational evaluator. Therefore, the results for each of the five attributes comprising the OEC developed earlier are used to construct a *matrix* of resulting OEC values, consisting of various combinations of the attribute importance coefficients. Various sets of weighting combinations can be selected and collected in a matrix format to provide the customer with a visual means of discerning between alternative configurations. Figure 8 illustrates the format of such an Evaluation Matrix.



Note: Baseline aircraft OEC = 1

Figure 8: Evaluation Matrix Format

In this example OEC matrix, the five attribute metrics are shown along with their appropriate importance coefficients. For example, α_1, α_2, and α_3 represent three different values for the importance coefficient for LCC, or Affordability. Immediately, it is seen that not every entry in the matrix will be populated since not all of the α, β, γ, δ, and ε combinations sum to one. For those combination which do make sense, a ratio appears in the box. The baseline values in the OEC (Equation (11)) correspond to the baseline aircraft whose OEC is always equal to one. Thus, returning to our example, if a comparison was desired Aircrafts A and B, Aircraft A could be considered the baseline and thus have its OEC equal to one. The OEC for Aircraft B, then, is calculated and entered into the appropriate cell of the matrix. If this number is *greater* than one, then the configuration B is a better overall configuration than its counterpart, for those particular choices of importance coefficients. Likewise, if the value entered is less than one, the Aircraft A is the better choice. In this way, an evaluator can quickly determine which aircraft is better for the given weighted objective function. Note that the attribute metrics themselves are constant throughout the matrix; it is only the coefficients which are changing.

A Summary

The three steps to concept selection described above (decomposition, recomposition, evaluation) are summarized in the Methodology Flow Diagram in Figure 9. The flow diagram maps the activities required, as well as the tools needed, to compute the required five attribute metrics. The sequence of events illustrated in Figure 9 represents the heart of the integrated approach to military aircraft selection and concept evaluation put forward in this paper. In summary, then, the first stage in the implementation consists of assessing the customer's needs and requirements (voice of the customer) and translating them into a series of objectives. This type of activity was illustrated in the Weapon System Effectiveness Breakdown of Figure 1. If the customer goals are broad, this decomposition process helps clarify the objectives and focus them through the creation of the OEC concept.

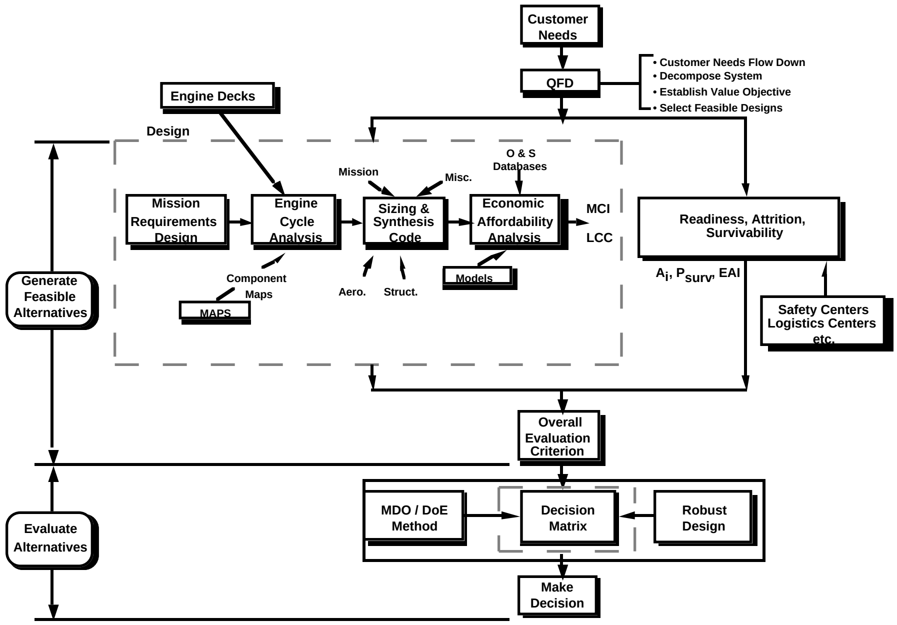


Figure 9: Methodology Flow Diagram

The second stage, termed "Generate Feasible Alternatives", is where the required metrics identified in the previous stage are calculated. The four main blocks of this stage, each representing a critical task, are the means by which the mission capability metric, MCI, and the Life Cycle Cost, LCC, are computed. The process begins, as with any design or analysis problem, with the definitions of all key requirements to be met. Subsequently, the powerplant performance is either specified externally or generated based and performance requirements. Subject to all appropriate constraints, the component weights of the aircraft generated by the sizing code are provided to the affordability analysis. Following this sequence of events, the MCI and the LCC are calculated, and the information is passed to the overall evaluation criterion. Finally, the availability, operational safety, and survivability metrics are calculated, concurrently where possible.

The final stage in the execution of the methodology is the Evaluation of Alternatives stage. Here, various combinations of the importance coefficients are considered resulting in a so-called OEC Decision Matrix.

Conclusion

The methodology developed and presented here represents an advancement in military aircraft design evaluation for two reasons. First, previous approaches concentrated mainly on narrow technology-cost tradeoffs. The approach presented here, in contrast, is a comprehensive way of addressing each of the five most important attributes of a military aircraft, not in isolation, but through an inclusive Overall Evaluation Criterion (OEC). These five attributes, as seen above, are Affordability, Capability, Operational Safety, Survivability, and Readiness. Second, this structured approach results in a series of outcomes which depend on the needs and/or preferences of the customer. Rarely are configuration choices clear cut, especially since subjective inputs are an inherent part of the decision making process. This Georgia Tech approach contains a *built-in* mechanism for such inputs in the OEC through what are called *attribute importance coefficients*. These coefficients are explicit entry points for the "voice of the customer," so that he may indicate his preferred importance weighting for air-to-ground capability, safety, affordability, etc. Once these weightings are chosen, a meaningful evaluation of alternative concepts can be made through comparisons of the non-dimensional OECs via an Evaluation Matrix, ultimately leading to the decision required.

References

1. Arnold, Wilbur V., "Designing Quality into Defense Systems", Defense Systems Management College, Fort Belvoir, Virginia, 1994.

2. "NASA HSCT Metrics Initiative", ASDL Study (Contracted by NASA Ames), Georgia Institute of Technology, To be Released July 1995.

3. Dieter, George E., Engineering Design. McGraw-Hill Publishers, Highstown, NJ, 1991.

4. Staff Interview, Department of the Navy, Naval Safety Center, Norfolk, Virginia, October 1994.

5. "User Documentation for the AFMC Logistics Support Cost Model, Version 2.2a," HQ AFMC / FMAC, Wright -Patterson AFB, Ohio, July 1993.